

ELECTRONIC FUNDAMENTALS

EXPERIMENT LESSON 26

IMPEDANCE-MATCHING EXPERIMENTS



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HOME STUDY SCHOOL
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Experiment Lesson 26

OBJECT

1. To study the transformation of impedances by a transformer.
2. To study the conditions for maximum transfer of power from one circuit to another.
3. To study a method of measuring the impedance of the speaker voice coil.

INTRODUCTION

The amount of power that can be transferred from one circuit to another depends upon the impedance of the two circuits. From your study of electron tubes, you have learned that the internal impedance of most electron tubes used as power-output amplifiers is generally high — on the order of thousands of ohms. You have also learned that the impedance of the voice coil of a loudspeaker is very low — usually less than 20 ohms. Due to this large difference in impedance, only a very tiny part of the power developed by the output stage can be transferred to the voice coil by direct connection.

In this lesson you will study the transfer of power from one circuit to another and determine experimentally what conditions are necessary for maximum power transfer. You will see how a transformer may also be used to step up or step down *impedances*, as well as voltages and currents. You will also see how this property of transformers is used to obtain maximum power transfer from one circuit to another.

Note: The accuracy of your results depends upon your following directions carefully. If you do these experiments carefully, your results should come close to the results given at the end of each experiment.

EQUIPMENT NEEDED

Radio-receiver chassis
Signal generator
Multimeter
1000-ohm, 5-watt resistor (from Kit 8)
Nichrome wire
Four flashlight cells
Piece of wood about 12 inches long
and 3 inches wide
Capacitor breadboard
Two grounding lugs
Two #6 wood screws
Hookup wire
Alligator clip lead

JOB 26-1

To prepare a slide-wire potentiometer.
Procedure.

Step 1. Cut off an 18-inch length of nichrome wire.

Step 2. Examine Fig. 26-1. Notice that a small nail is shown hammered into the board. The nail is close to one short edge of the board and about half way between the long edges. Hammer a nail part way into your board in about the same position.

Step 3. Loop the 18-inch length of nichrome wire around the nail so that half of it extends on either side of the nail. Bring the ends of the wire down to form a loop shaped like the one in Fig. 26-1. Notice that the ends of the loop are to be mounted under

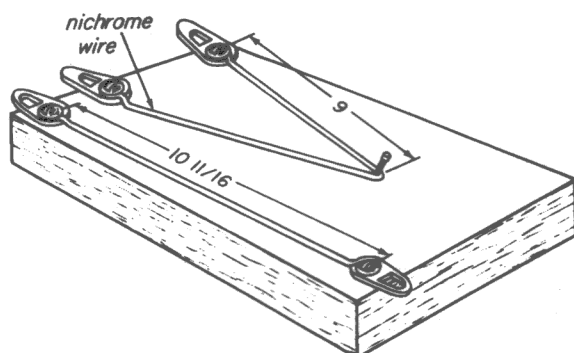


Fig. 26-1

the heads of the screws. Position, but do not screw in, the screws on the board at just about the ends of the wire loop, leaving enough of the wire extending so the ends of the nichrome wire can be wrapped under the head of each screw. Slip one of the grounding lugs on each screw. Start the screws into the board. Just before you take the last few turns that will tighten the head of the screw against the board, wrap the ends of the nichrome wire under the heads of the screws. There should be practically no slack in the wire. Then tighten the screws so their heads are against the board. When the screws are tightened, the wire should be tight and making good electrical contact with the grounding lugs.

Step 4. Starting at one of the wood screws, place a mark every $1\frac{3}{4}$ inches along the wire, as shown in Fig. 26-2. (If you have a rule calibrated in 32nds of an inch, and you want to be very accurate, place your marks at $1\frac{25}{32}$ inch intervals.)

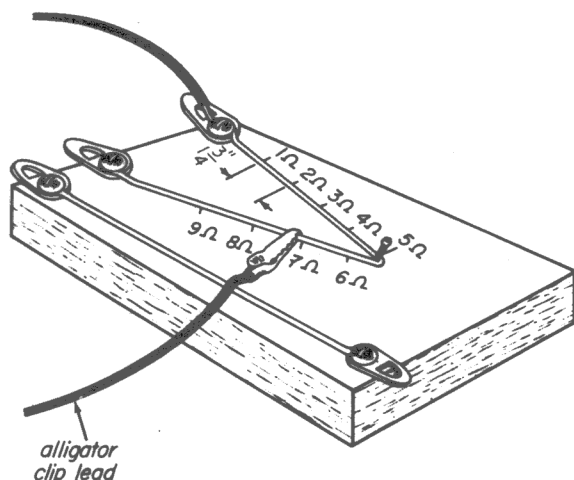


Fig. 26-2

Step 5. The #30 gauge nichrome wire that you have received has a resistance of 6.75 ohms per foot, or 1 ohm for $1\frac{3}{4}$ inches. Label the marks that you have made, starting with 1 ohm, 2 ohms, etc., up to 9 ohms. Then divide each interval in half, so that you have a calibrated scale as shown in Fig. 26-2.

Step 6. Connect a 12-inch piece of hookup wire to the grounding lug at the low end of the scale, and connect one end of your alligator clip to the nichrome wire, as shown in the figure. Your calibrated slide-wire variable potentiometer is now complete.

Step 7. Cut off a 12-inch piece of nichrome wire.

Step 8. Remove two of the vacant grounding lugs from your capacitor board and mount them near the edge of the board on which you are working so that they are $10\frac{11}{16}$ inches apart. Before the screws are tightened down, as in Fig. 26-1. Fasten the piece of nichrome wire between the two lugs, as described in Step 3. The resistance between these lugs is 6 ohms.

Step 9. Prepare a 3-volt battery by connecting 4 flashlight cells in series-parallel with alligator clip leads for the battery terminals, as shown in Fig. 26-3.

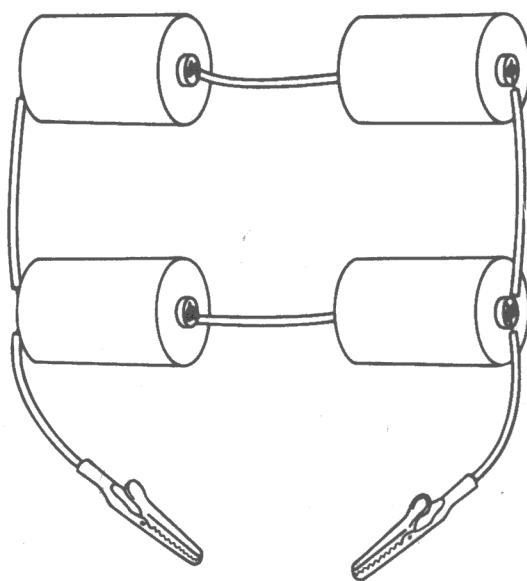


Fig. 26-3

EXPERIMENT 26-1.

To study a method of measuring the internal impedance of a generator.

Information. In this Experiment Lesson we are going to study how the power transmitted from a generator to a load depends upon the ratio of the load impedance to the generator impedance. Our first step, therefore, is to study a method of measuring the internal impedance of a voltage source, such as a battery or signal generator.

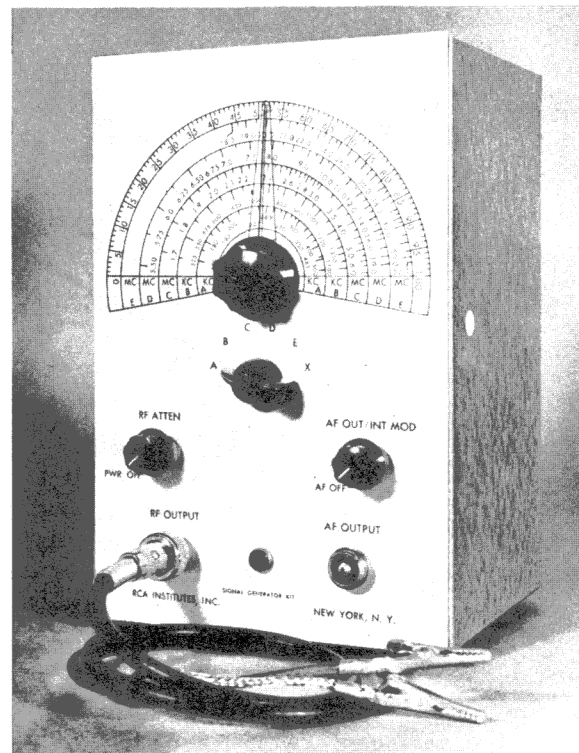
Suppose that we have a voltage source, such as the signal generator shown in Fig. 26-4a. It can be represented, as shown by Fig. 26-4b as a constant-voltage generator whose voltage is E , in series with a certain internal impedance R_{int} . If we knew the voltage drop across R_{int} , and the current flowing through it, the value of R_{int} could be found by Ohms Law.

$$R_{int} = \frac{E}{I}$$

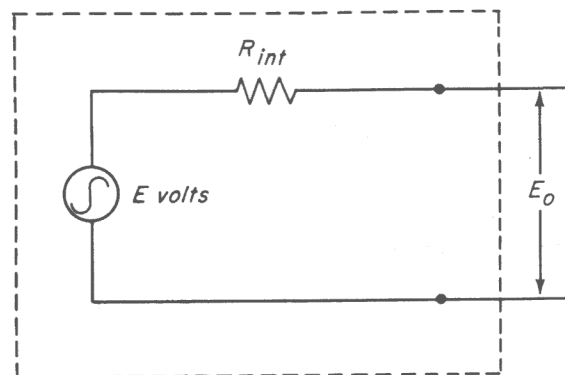
However, we cannot measure the voltage drop across R_{int} . But it can be found as follows: The voltage across the terminals of the generator is first measured without any load across the terminals. Since the meter resistance is very high, practically no current flows. There is no drop voltage across R_{int} and the voltage indicated by the meter is practically the generated voltage. This voltage is termed the open-circuit terminal voltage, and we will call it E_o . If a known load resistance R_L is placed across the terminals, as in Fig. 26-4c, current will flow, and the voltage across the load, E_L , will be less than the open circuit voltage. The current through the internal resistance is the same as the current through the load, and is given by:

$$I = \frac{E_L}{R_L}$$

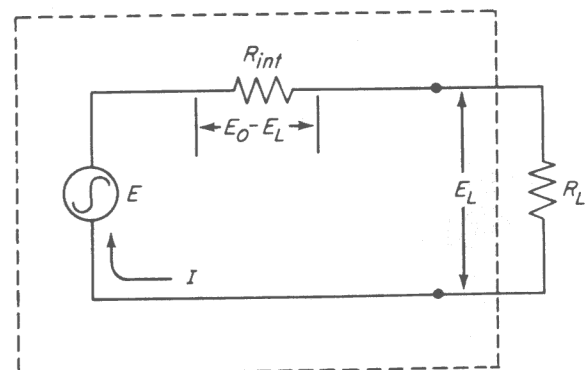
The value of R_{int} , which is equal to the voltage across it divided by the current



(a)



(b)



(c)

Fig. 26-4

Experiment 26-1

through it is given by:

$$R_{int} = \frac{E_o - E_L}{\frac{E_L}{R_L}} = (E_o - E_L) \times \frac{R_L}{E_L}$$

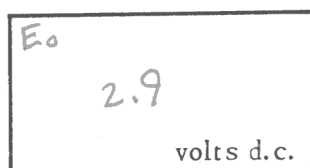
In this experiment, a voltage source and its internal impedance will be simulated by the 3-volt battery in series with a small resistance, as in Fig. 26-5.

Procedure.

Step 1. Connect the 4 cells in series with the 6-ohm resistance that has been mounted on the capacitor board, as shown in Fig. 26-5. (Do not connect the clip lead to A')

Step 2. Set up the multimeter to the 5 VDC range.

Step 3. Measure the voltage across the terminals A - A'. This is the open circuit voltage, E_o . Record this voltage here:



Step 4. Adjust the alligator clip on the slide-wire potentiometer so that there is a total of 5 ohms between the potentiometer terminals. Adjust the alligator clip to grip the nichrome wire at the very tip of the clip, and make sure it is holding the wire tightly. Connect the other alligator clip to terminal A'.

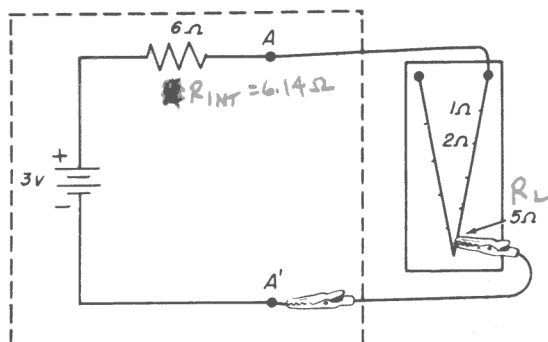
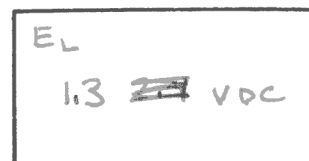


Fig. 26-5

Step 5. Measure the voltage across the load at these terminals. Measure the voltage quickly and open the circuit at A' as soon as the reading is made, because the drain on the batteries is very high. This is the load voltage, E_L . Record this voltage here:



Step 6. Calculate the internal impedance.

$$R_{int} = (E_o - E_L) \times \frac{R_L}{E_L} = (2.9 - 1.35) \times \frac{5}{1.35} = 1.6 \cdot 3.84 = 6.144$$

How does this value compare with the known value of R_{int} ?

Discussion. Typical results for this experiment are as follows:

Open circuit voltage (E_o) - 3 volts

Load voltage (E_L) - 1.35 volts

Internal resistance (R_{int}) - 6.11 ohms

If the cells used are not very exhausted, so that their internal impedance is not very high, the calculated value will be very close to the actual value of the series resistance. In any case, the procedure given in this experiment determines the total impedance of the voltage source.

EXPERIMENT 26-2.

To study how the transmitted power in a d-c circuit changes as the load resistance is varied.

Information. In this experiment you will use the voltage source which you constructed and whose internal impedance you measured in the previous experiment. You will connect various loads across this voltage source, by means of the calibrated slide-wire potentiometer, and determine the

power delivered to each of these loads. By plotting the power against the load resistance, you will be able to see under what conditions maximum power is transferred. The power to the load P is determined by measuring the voltage E across the load, R_L and using the formula:

$$P = \frac{E^2}{R_L}$$

Procedure.

Step 1. Use the circuit set-up shown in Fig. 26-5.

Step 2. Set up the multimeter to the 5 VDC range.

Step 3. Adjust the alligator clip to the 1-ohm point on the slide wire potentiometer.

Step 4. Close the circuit by connecting the other alligator clip P_1 to terminal A' . Quickly measure the voltage across the load (terminals $A - A'$), and open the circuit. Enter your readings in Table A.

Step 5. Adjust the alligator clip P to the next resistance value called for in the table, and quickly measure the voltage across the load. Continue in this way until you have filled out the second column of the table.

Step 6. Calculate the power in the load for each value of load resistance in the table, using the formula:

$$P_L = \frac{E^2}{R_L}$$

Step 7. Plot the load power against the load resistance on the graph paper provided at the back of this booklet. Convert the figures for power to milliwatts on the power axis of the curve you plot.

How does the value of load resistance at which maximum power is obtained compare with the value of the resistance in series

TABLE A

Load Ohms	Load Voltage (volts)	Load Current (amperes)	Load Power (watts)
1.0	.45	.45 a	.2025
2.0	.7	.35 a	.245
2.5	.83	.33 a	.283
3.0	.94	.31 a	.295
3.5	1.03	.29	.303
4.0	1.12	.28	.313
5.0	1.3	.26	.338
6.0	1.42	.23	.336
6.5	1.46	.22	.327
7.0	1.5	.21	.321
7.5	1.56	.208	.324
8.0	1.6	.200	.320
8.5	1.64	.19	.316
9.0	1.7	.18	.321

with the voltage source?

Discussion. When your table is completed and your graph is plotted, they should show that maximum power is developed in the load resistor when the load resistor is equal in value to the internal resistance of your voltage source. The 6-ohm piece of nichrome wire has been considered to be the internal resistance of your voltage source. Therefore, maximum power to the load should occur when the load resistance is also about 6 ohms. Typical results that we obtained for this experiment are shown in Table B, and a graph of power load versus load resistance plotted from the values in this table is given in Fig. 26-6.

EXPERIMENT 26-3.

1. To study how a transformer may be used to step up or step down impedances.

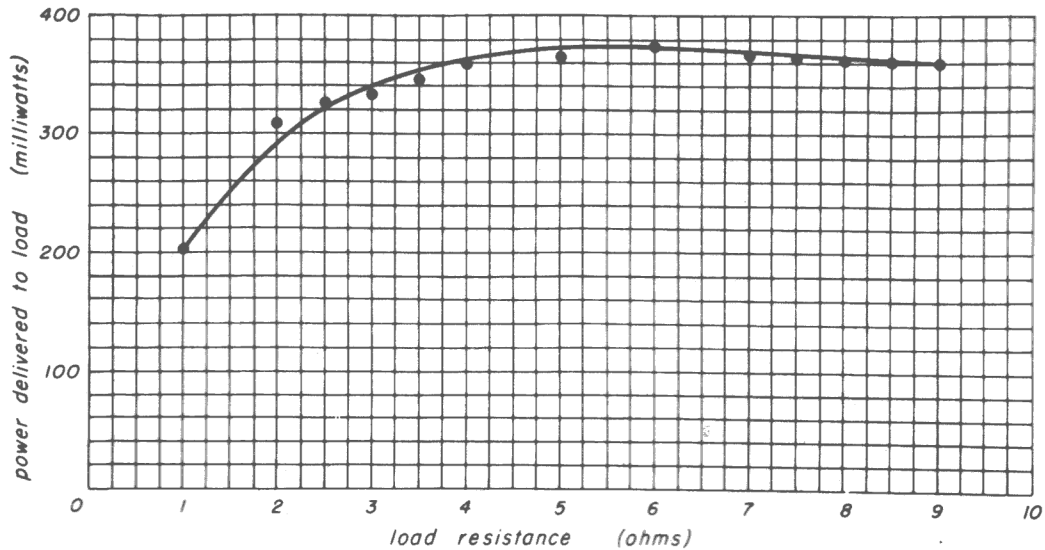


Fig. 26-6

2. To determine the turns ratio of the output transformer.

Information. You have learned that maximum power is transferred when the impedance of the source and load are matched. Therefore, very little power can be

transferred by direct connection from an output tube whose plate resistance is many thousands of ohms to a speaker voice coil whose impedance is only a few ohms (Fig. 26-7).

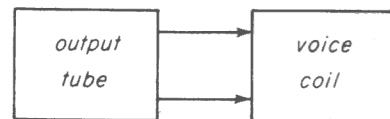


Fig. 26-7

TABLE B

Load Ohms	Load Voltage (volts)	Load Current (amperes)	Load Power (watts)
1.0	0.45	0.45a	0.207
2.0	0.8	0.4	0.32
2.5	0.9	0.36	0.324
3.0	1	0.33	0.333
3.5	1.1	0.314	0.346
4.0	1.2	0.3	0.36
5.0	1.35	0.27	0.364
6.0	1.5	0.25	0.376
6.5	1.55	0.239	0.37
7.0	1.6	0.228	0.366
7.5	1.65	0.22	0.363
8.0	1.7	0.213	0.364
8.5	1.75	0.206	0.3605
9.0	1.8	0.2	0.3600

However, both the plate resistance of the tube and the impedance of the speaker voice coil are fixed. The plate resistance of the tube cannot be lowered without affecting its proper operation as a power amplifier. The impedance of the voice coil must remain very low because it cannot have too many turns of wire or it will have too much inertia. By placing an impedance-matching device between the output tube and the speaker voice coil, as shown in Fig. 26-8, the output tube can be made to see a high impedance, and the voice coil can be made to see a low impedance. This impedance-changing device is the transformer. The impedance ratio of a transformer is equal to the square of its turns ratio.

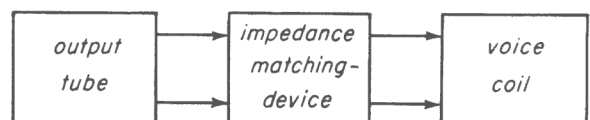


Fig. 26-8

Procedure.

Step 1. Disconnect the primary and secondary leads of the output transformer.

Step 2. Temporarily solder the primary leads to lugs 1 and 2 of TS-A.

Step 3. Set up your multimeter to the 300 VAC range.

Step 4. Plug in the receiver line cord, and measure the input to the primary of the output transformer, across TS-A. Record your readings here:

124
volts a.c.

Step 5. Set your meter range switch to the 15 VAC range.

Step 6. Measure the voltage output of secondary winding of the output transformer (across the voice coil leads).

Record your reading here:

2.1
volts a.c.

Step 7. Unplug the line cord.

Step 8. Determine the voltage ratio of transformer:

$$\text{Voltage ratio} = \frac{\text{input}}{\text{output}} = \frac{124}{2.1} =$$

Step 9. The turns ratio of the transformer is equal to the voltage ratio. Note the turns ratio of the transformer here:

59
1
turns ratio

Discussion. Although this transformer is not designed for best operation at 60 cycles, its turns ratio may be determined with reasonable accuracy using a 60 cycle a-c signal, as you have done in this experiment. In our laboratory, with 120 volts input to the primary, 2.4 volts was measured across the voice coil winding. The turns ratio is therefore:

Turns ratio = voltage ratio

$$= \frac{120}{2.4} = \frac{50}{1}$$

The turns ratio is 50:1. In our laboratory, the same turns ratio was also obtained using a 400-cycle signal. In the next experiment, you will see how the impedance ratio is related to the turns ratio.

EXPERIMENT 26-4

To determine the impedance ratio of the output transformer, and to study *reflected impedance*, that is, how the impedance connected to the secondary winding of a transformer affects the impedance of the primary winding.

Procedure.

Step 1. Disconnect the primary leads from TS-A.

Step 2. Connect the 1,000-ohm 5-watt resistor across lugs 1 and 2 of TS-F.

Step 3. Connect the red lead of the output transformer to lug 1 of TS-F, and the blue lead of the output transformer to pin 3 of the 6K6-GT tube socket.

Step 4. Connect a lead from lug 2 of TS-F to the  (semicircle) section of the electrolytic capacitor.

Step 5. Disconnect the 0.05-μf capacitor at lug 1 of TS-E and let it hang free.

Step 6. Connect a 12-inch length of wire to each of the secondary leads and connect

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107
1/90

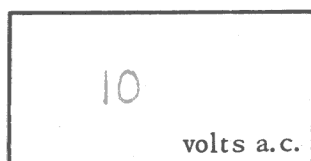
the other end of each lead to the end terminals of the slide-wire potentiometer as in Fig. 26-9.

Step 7. Connect one end of your alligator-clip lead to the high-resistance terminal of the slide-wire potentiometer, and the other end of this clip lead to the nichrome wire at the 1-ohm point on the wire as shown in the figure. Compare your wiring with the schematic of Fig. 26-9 before you proceed.

Information. The 1,000-ohm resistor inserted in series with the primary winding of the output transformer is used to determine the a-c current flowing in the circuit. The current is found by dividing the a-c voltage measured across the resistance by the value of the resistance. Since this is a series circuit, the same current flows through the primary winding. The impedance of the primary winding is found by dividing the voltage across the primary, E_L , by the current.

Step 8. Make sure that power is disconnected from the receiver. Carefully zero the ohmmeter. Set the meter to the R X 100 scale, and measure the actual resistance of the 1,000-ohm resistor across TS-F.

Step 9. Calculate the voltage across the resistor, using its actual resistance. Assume 10 ma of current is flowing through it. (For example, if the actual resistance is 900 ohms and 10 ma of current is flowing through it, the voltage across the resistor is 9 volts.



Step 10. Plug in the signal generator and allow it to warm up. Turn the bandswitch to Band X, and connect the output cable to the the AF OUTPUT jack.

Step 11. Plug in the receiver, and allow the tubes to warm up.

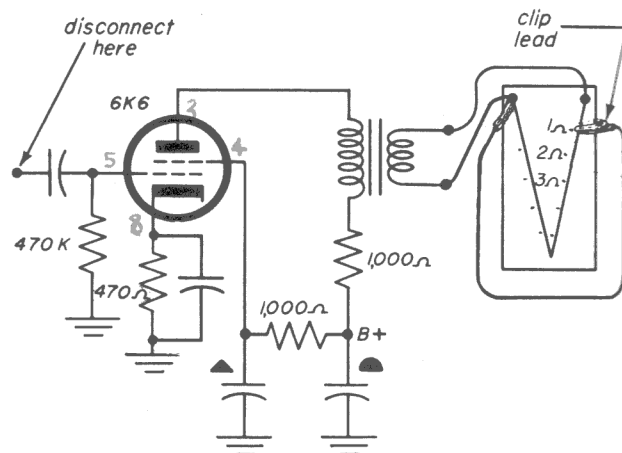


Fig. 26-9

Step 12. Connect the signal generator to the grid of the 6K6-GT tube and ground.

Step 13. Set up the multimeter to the 75 VAC range, and put the positive lead in the output jack.

Step 14. Connect the meter between lugs 1 and 2 of TS-F (1,000 ohm resistor) and adjust the signal generator output so that the voltage you calculated in Step 9 is produced across the resistor. When this voltage is across the resistor, 10-ma a.c. flows in this series circuit.

Step 15. Measure the voltage across the primary winding, and record it in the E_L column of Table C on the 1-ohm line.

Step 16. Adjust the slide-wire potentiometer to 2 ohms, the next value called for in the table, and repeat Steps 14 and 15. Continue in this manner until you have made all the voltage readings called for in the table. Readjust the signal generator output each time if necessary to maintain constant voltage across the 1,000-ohm resistor.

Step 17. Disconnect the receiver line cord.

Step 18. Disconnect and remove the lead from lug 2 of TS-F to the  section of the electrolytic capacitor.

Step 19. Disconnect and remove the 1,000-ohm resistor across TS-F.

Step 20. Connect the red lead of the output transformer to the  section of the electrolytic capacitor.

Step 21. Use the following formula to calculate the primary impedance for each setting of the slide wire potentiometer. Fill out the impedance column of the table.

$$Z = \frac{E_L}{10 \text{ ma}}$$

Step 22. Divide the primary impedance by the impedance connected to the secondary to obtain the impedance ratio, and fill out the last column of Table C.

TABLE C

Load Resistance (ohms)	E_L (volts)	Z_L (ohms)	Z_{Ratio} (ohms)
1	41	4100	4100
2	64	6400	3200
3	76	7600	2533
3.2	84	8400	2625
4	92	9200	2300
5	102	10200	2040
6	109	10900	1816

How does the impedance ratio compare with the turns ratio determined in Experiment 26-3?

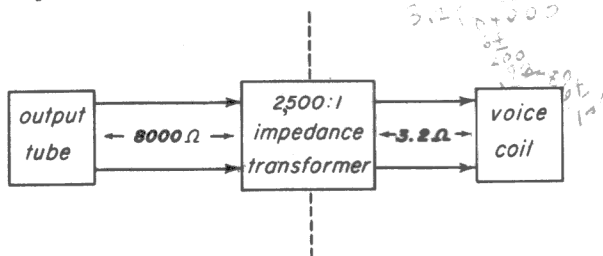


Fig. 26-10

Discussion. Your results for this experiment will show that the impedance looking into the primary winding depends upon what is connected to the secondary winding. In other words, changing the load connected to the secondary winding changes the impedance of the primary winding. The impedance

ratio between the primary and secondary is about 2,500:1, when a load of 3.2 ohms is across the secondary. The square root of this number is equal to the turns ratio (50:1).

Any load connected to the secondary is reflected back into the primary as a load 2,500 times as great. A 3.2-ohm voice coil connected to the secondary winding appears as an impedance of $3.2 \times 2,500$ or 8,000 ohms in the primary winding. This is the principle of impedance matching. As seen in Fig. 26-10, when looking from left to right, the transformer multiplies impedance by 2,500, so that the load presented to the output tube is 2,500 times the voice-coil impedance, or 7,600 ohms. This is close to the load recommended in the tube manual (7,600 ohms) as the proper load impedance for this tube. Looking from right to left, the transformer divides impedance by 2,500 ohms, so the impedance presented to the voice coil is 3.2 ohms. Thus, through the impedance-matching property of the transformer, the output tube is matched to the voice coil.

Typical results for this experiment are shown in Table D. Your results should be about $\pm 10\%$ of the results shown. Transformers of this type are usually held to within 10%.

JOB 26-2.

To prepare a meter amplifier for use in the next experiment.

TABLE D

Load Resistance (ohms)	E_L (volts)	Z_L (ohms)	Z_{Ratio} (ohms)
1	41	4.1 K	4,100
2	61	6.1 K	3,050
3	78	7.8 K	2,600
3.2	80	8 K	2,500
4	96	9.6 K	2,400
5	110	11 K	2,200
6	120	12 K	2,000

$\sqrt{2625}$
51
101

101 14100

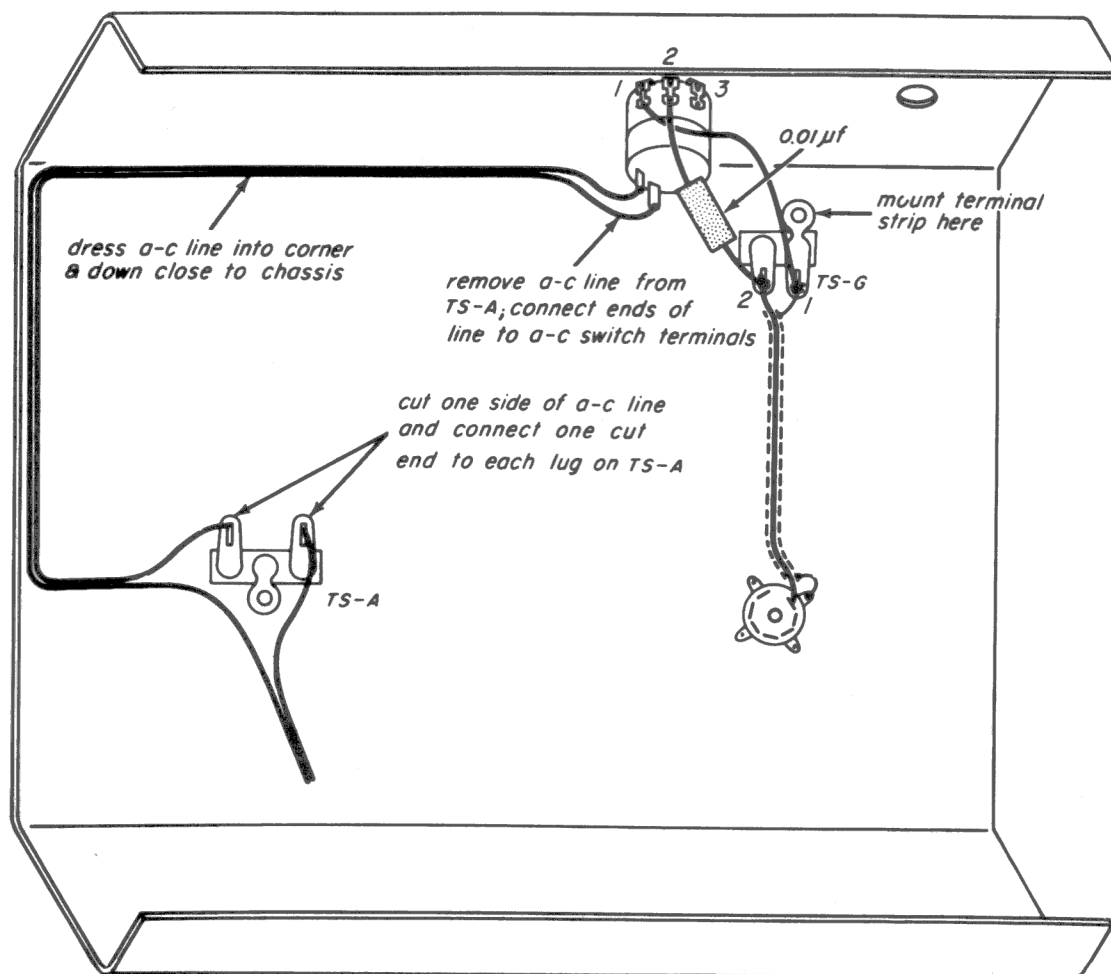


Fig. 26-11

Information. In order to perform the next experiment, very low voltages must be measured. These voltages are too low to be measured with your meter. By arranging your 6AT6 voltage-amplifier stage to be used as a meter amplifier, your meter can be used to measure these small voltages. The circuit that you wire will introduce you to the principle of vacuum-tube voltmeters, even though it is not identical to the circuit used for vacuum-tube voltmeters.

Note: This experiment will succeed only if you pay careful attention to details and make the various settings and measurements called for accurately.

Procedure.

Step 1. Mount a terminal strip of the type shown in Fig. 26-11 at the location indicated in the figure. This terminal strip will be referred to as TS-G. Label the terminal strip on your chassis.

Step 2. Connect a lead from terminal 1 of the 500 k-ohm potentiometer mounted on the chassis to lug 1 (the grounding lug) of this terminal strip. Dress this lead away from the a-c switch terminals.

Step 3. Connect an $0.01\text{-}\mu\text{f}$ capacitor between the center terminal of the potentiometer, and lug 2 of TS-G.

Step 4. Remove the braided covering from each end of the piece of shielded lead that you received in Kit 13, using the method described in Experiment Lesson 2. Connect the center conductor of the shielded lead from lug 2 of TS-G to pin 1 of the 6AT6 tube socket. Dress the lead as shown in the figure. Ground the shield at both ends – at the ground pin near pin 1 on the tube socket, and at the ground lug at TS-G. Compare your chassis with wiring shown in Fig. 26-11 and

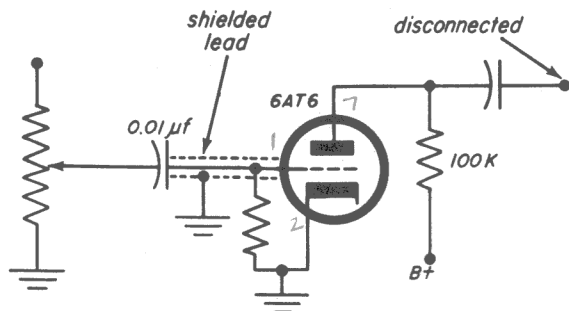


Fig. 26-12

the circuit diagram shown in Fig. 26-12.

Step 5. Remove the line cord from TS-A and connect the line cord across the a-c switch terminals of the potentiometer. Cut *one side* of the line cord at a point 13 inches from the end. Strip 1/2-inch of insulation from each end of the cut. Dress the line cord, as shown in the figure, and solder each of the newly cut ends to lugs 1 and 2 of TS-A. You may now use the a-c switch to turn the receiver on and off. But remember that the terminals of TS-A are always "live" whenever the line cord is plugged into an a-c outlet, and the switch is on.

Step 6. Connect the 100,000-ohm, 10,000-ohm and 1,000-ohm resistors on the resistor board in series.

Step 7. Using as short a lead as possible, connect terminal 3 of the potentiometer to the junction of the 10 k-ohm and 100 k-ohm resistors on the resistor board. Also, connect a lead from the free end of the 1,000-ohm resistor to chassis.

Step 8. Disconnect the lead of the 100 k-ohm resistor at lug 2 of TS-C and solder this lead to lug 1 of TS-C.

Step 9. Turn on the receiver and the signal generator. Allow them to warm up. Set the generator bandswitch to Band X and connect the cable to the AF OUTPUT jack.

Step 10. Set up the multimeter to the 15 VAC scale of the meter and connect the meter across the signal generator leads. Carefully adjust the output of the signal generator to give 10 volts as indicated on the meter. Do not disturb the AF OUT/INT MOD

control setting once this adjustment has been accurately made.

Step 11. Connect the center conductor of the cable to the free end of the 100 k-ohm resistor, and the ground conductor of the cable to the ground end of the 1,000 ohm resistor, as shown in Fig. 26-13.

You have used the arrangement of Fig. 26-13 before. It is a 10:1 resistive voltage divider. Since 10 volts is being applied to the divider, the output is 1 volt. This method is more accurate than trying to measure 1 volt directly with your meter.

Step 12. Insert the positive meter lead in the OUTPUT jack. The meter is still set up to the 15 VAC range. Connect the positive meter lead to the plate of the 6AT6 tube and the other meter lead to chassis and adjust the volume control carefully until the meter indicates 10 volts. *Do not disturb the volume-control setting once this adjustment is accurately made.* Turn the receiver off by pulling out the line cord.

Step 13. Disconnect the signal generator and the resistors on the board. The free lead from the potentiometer is now to be used as the meter test lead. We will call it test lead *T*. The combination of the meter and the 6AT6 has a gain of 10, and the meter will indicate 10 times the actual

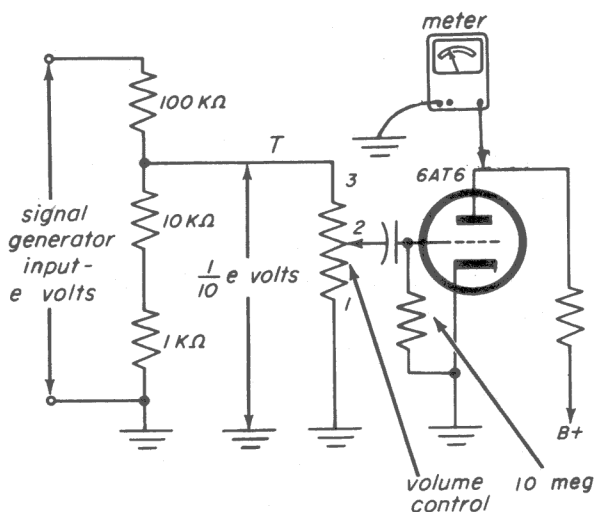


Fig. 26-13

voltage of any signal applied to test lead *T*. Therefore, the 0-15 VAC scale of the meter now becomes a 0-1.5 VAC scale. The meter is connected across the 100 k-ohm resistor in the 6AT6 plate circuit.

EXPERIMENT 26-5

To determine under what conditions maximum power is transferred from the output tube to the voice coil.

Information. In this experiment, you will connect your slide wire potentiometer across the secondary of the output transformer, and vary the load on the secondary from about 1 ohm to 6 ohms. The power transferred to the load is determined by measuring the voltage across the load and using the formula E^2/R . By plotting the power output to the load against the load resistance, you will be able to see how the transmitted power varies with the load resistance connected to the secondary winding.

Procedure.

Step 1. Check to see that the slide-wire potentiometer is connected across the secondary leads, as in Fig. 26-9.

Step 2. Connect a short test lead *T* (from terminal 3 of the potentiometer) to the alligator clip of the test lead that contacts the slide wire.

Step 3. Connect a short lead between the low-resistance end (terminal near the zero ohms mark) and the chassis.

Step 4. Connect the radio receiver and the signal generator to a-c power and allow the tubes to warm up.

Step 5. Connect the high side of the signal generator cable to the loose end of the 0.05- μ f capacitor that is connected to the control grid (pin 5) of the 6K6-GT tube, and the ground side to the chassis.

Step 6. Adjust the output of the signal generator to produce 0.1 volt across the

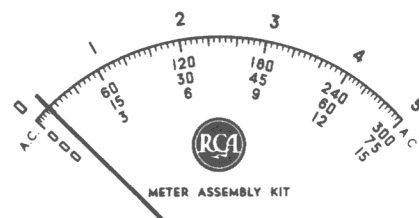


Fig. 26-14

1-ohm secondary load. Remember that the meter is connected across the 100 k-ohm resistor in the 6AT6 plate circuit. Remember that the 15 VAC scale is now a 0-1.5 volt scale, so 0.1 volt is at the position shown in Fig. 26-14.

Step 7. Adjust the slide-wire potentiometer to 2 ohms, and measure the voltage across the secondary load. Enter your reading in Table E.

Step 8. Adjust the slide-wire potentiometer to 3-ohms, the next value called for in the table, and measure the voltage across the load, and enter the reading in the table. Continue until you have filled out the Voltage Across Load column of Table E. Turn off the receiver by pulling out the line cord.

Step 9. The following formula is used for calculating the power delivered to a load:

$$P = \frac{E_L^2}{R}$$

Use this formula to find the power for each value of load resistance in Table E. List your results in the last column of Table E.

TABLE E

Load Resistance (ohms)	Voltage Across Load (volts)	Power Delivered To Load (watts)
1	.1	.01
2	.16	.0128
3	.22	.0161
3.2	.22	.015
4	.26	.0169
5	.28	.0156
6	.31	.0160

Step 10. On the graph paper provided at the end of this lesson, plot the power delivered to the load against load resistance.

Use the X axis for load resistance and the Y axis for power delivered to the load. Convert the values for power into milliwatts on the power axis of your curve.

At what value of load resistance is maximum power obtained?

How does this value compare with the impedance of the voice coil for which this output transformer is designed?

What impedance does the output tube "see" when maximum power is delivered to the voice coil?

How does this compare with the recommended load for the tube given in the tube manual?

Discussion. If you have performed this experiment accurately, and kept your leads short and direct, you will have obtained the correct results.

The results of your experiment should show that the maximum power is delivered to the load when it is approximately 3.2 ohms. At this value of secondary-load resistance, the output tube sees a resistance approximately 2,375 times greater, or 7,600 ohms. This is the value of load resistance recommended in the tube manual for maximum power output. In a pentode-tube power amplifier, a proper choice of the load resistance gives maximum power output along with minimum distortion.

Results for this experiment are given in Table F, and a graph of load power against load resistance plotted from this data is shown in Fig. 26-15.

EXPERIMENT 26-6.

To study a method of measuring the impedance of a speaker voice coil.

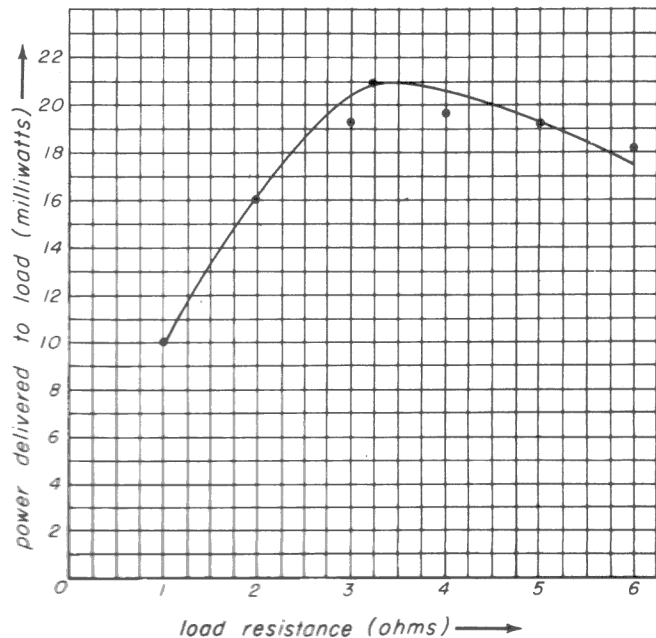


Fig. 26-15

Information. When a source of voltage is connected across the series combination of an *unknown* impedance and a *known* resistance as in Fig. 26-16, the voltage drop

TABLE F

Load Resistance (ohms)	Voltage Across Load (volts)	Power Delivered To Load (watts)
1	0.1	0.01
2	0.18	0.0162
3	0.24	0.0192
3.2	0.26	0.021
4	0.28	0.0196
5	0.31	0.0192
6	0.33	0.0182

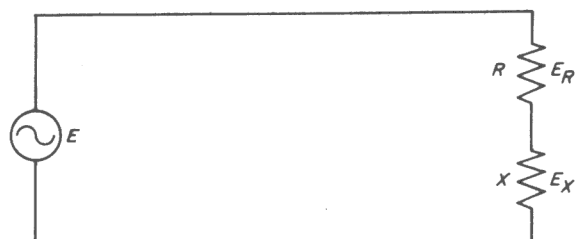


Fig. 26-16

$$\begin{array}{l} .56 = \frac{5}{X} \\ .37 = 1.85 \\ .56X = 1.85 \\ 168 \\ 170 \end{array} \quad \begin{array}{l} 3.2 \\ 49 \overline{) 160.0} \\ 147 \\ 130 \\ 98 \end{array} \quad \begin{array}{l} .49 = \frac{4}{X} \\ 14 \\ .49X = 1.6 \end{array} \quad \begin{array}{l} .39 = \frac{3}{X} \\ .45 \\ .39X = 1.35 \end{array} \quad \begin{array}{l} .27 = \frac{2}{X} \\ .5 \\ .27X = 1 \end{array} \quad \begin{array}{l} .27 \overline{) 1.00} \\ 81 \\ 190 \end{array}$$

Experiment 26-7

15

across each of them will be in direct proportion to the size of their impedances. Thus:

$$\frac{E_R}{E_X} = \frac{R}{X}$$

If the resistance of R is accurately known, the impedance of X can be found by the following formula:

$$X = \frac{E_X}{E_R} \times R$$

If R is a variable resistor, it can be adjusted until:

$$E_R = E_X$$

At this point, $R = X$. If R is an accurately calibrated resistor, the value of the impedance of X in ohms can be read directly from the resistor. If R is not calibrated, its resistance can be measured with an ohmmeter to find the value of X in ohms.

Procedure.

Step 1. Disconnect the previous circuit on the secondary side of the transformer. Connect the speaker voice coil and the slide-wire potentiometer in series, as shown in Fig. 26-17.

Step 2. Connect the junction of the voice coil and the potentiometer to the chassis, as shown.

Step 3. Move the alligator clip on the slide wire to the 2-ohm point.

Step 4. Plug in the receiver and signal generator and allow the tubes to warm up.

Step 5. If the volume-control setting has been disturbed, recalibrate the meter amplifier as previously described.

Step 6. Connect the signal generator through the 0.05- μ f capacitor to the grid of the 6K6-GT tube.

Step 7. Touch test lead T (from the high side of the volume control) to the ungrounded side of the voice coil.

Step 8. Adjust the output of the signal generator to obtain 0.5 volts across the voice coil. (Remember that the meter is connected across the 6AT6 plate lead.)

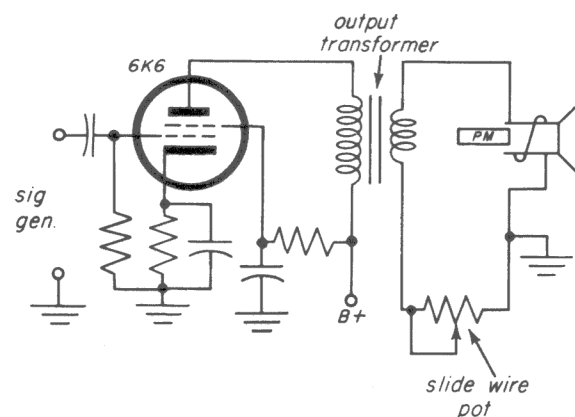


Fig. 26-17

Step 9. Touch test lead T to the ungrounded side of the potentiometer, and measure the voltage across the potentiometer. Enter the reading in the first line of Table G.

Step 10. Adjust the slide-wire potentiometer to each of the other values called for in the table, and measure the voltage across the voice coil and the resistor until the table is filled out.

TABLE G

R (ohms)	E_R (volts)	E_X (volts)	Z_X (ohms)
2	.27	.5	3.7
3	.39	.45	3.4
4	.49	.4	3.2
5	.56	.37	3.3

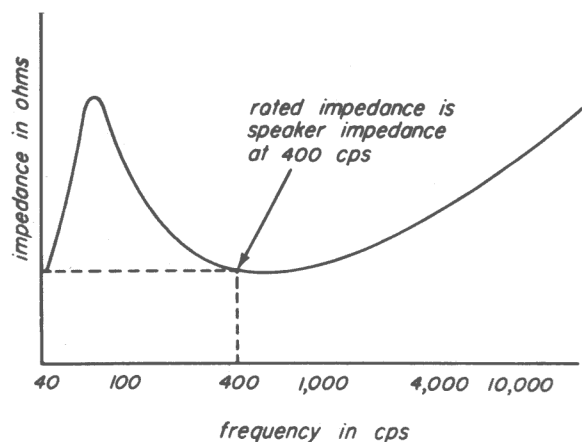


Fig. 26-18

Step 11. Vary the slide-wire potentiometer back and forth while measuring the voltage across both voice coil and resistor until they are equal. From your calibrated scale, estimate as carefully as possible the value of resistance at which this occurs. Enter your reading here:

3.4

ohms

Step 12. Unplug the receiver and the signal generator. Disconnect the slide wire potentiometer from the circuit, and put it aside.

Step 13. Reconnect the output-transformer secondary leads to the loudspeaker voice-coil terminals.

Step 14. Reconnect the $0.05\text{-}\mu\text{f}$ capacitor from the grid of the 6K6-GT tube to lug 1 of TS-E.

TABLE H

R (ohms)	E_R (volts)	E_X (volts)	Z_X (ohms)
2	0.28	0.46	3.29
3	0.4	0.42	3.15
4	0.5	0.4	3.2
5	0.58	0.37	3.19

Step 15. Disconnect and remove the lead connected to the high side of the potentiometer.

Step 16. Calculate the impedance of the voice coil for each pair of readings taken, using the formula given above, and enter these results in Table G.

Discussion. In our laboratory, equal voltages of 0.42 volts were obtained across voice coil and slide-wire potentiometer when the potentiometer was adjusted to 3.2 ohms.

The impedance of the speaker voice coil varies with frequency in the manner shown in Fig. 26-18. Manufacturers usually give the impedance of the voice coil at 400 cycles. Since the audio output of your signal generator is 400 cycles, you can compare your results with the rated value. Typical results for this experiment are given in Table H.

